BELLCOMM, INC.

SUBJECT: Venus Swingbys for Manned Mars Missions During the 1978-1986 Period
Case 103-2

DATE: August 9, 1966

FROM: A. A. VanderVeen

MEMORANDUM FOR FILE

The attached paper was presented by the author to the Space Flight Mechanics Specialist Conference of the American Astronautical Society on July 8, 1966, in Denver, Colorado.

A. A. VanderVeen

A. A. VanderVeen

1021-AAV-wlm

Attachment

Copy to
Messrs.

F. P. Dixon - NASA/MTY
E. Z. Gray - NASA/MT
T. A. Keegan - NASA/MA-2
D. R. Lord - NASA/MTX
A. D. Schnyer - NASA/MTV

M. A. Silveira - MSC/ET-25
W. E. Stoney - MSC/ET
P. G. Thomas - MSC/ET-23
J. M. West - MSC/AD

B. G. Noblitt - MSFC/R-AERO-XA
A. C. Young - MSFC/R-AERO-DPF

F. G. Allen
G. M. Anderson
J. O. Cappellari, Jr.
K. R. Carpenter
D. E. Cassidy
R. E. Gradle

Copy to
Continued - Over

Copy to
Messrs. D. R. Hagner
P. L. Havenstein
J. A. Hornbeck
B. T. Howard
D. B. James
J. E. Johnson
A. N. Kontaratos
B. H. Liebowitz
M. Liwshitz
J. L. Marshall
J. Z. Menard
G. T. Orrok
R. Y. Pei
I. M. Ross
J. A. Saxton
J. J. Schoch
A. L. Schreiber
R. V. Sperry
T. H. Thompson
W. B. Thompson
J. M. Tschirgi
R. L. Wagner
Central Files
Department 1023
Library

VENUS SWINGBYS for MANNED MARS MISSIONS

DURING the 1978-1986 PERIOD

Arthur A. Vander Veen+

The Venus swingby mode of manned Mars missions is investigated in depth to determine if this mode can be effectively used to extend the window of available launch opportunities during the 1978-1986 period. Velocity contours are plotted in two and three dimensions to reveal the undulating characteristics of the Venus swingby trajectory surfaces. It is noted that certain regions of a trajectory surface may overlap or be otherwise obscured from view, when the contours are plotted in the conventional manner. The criterion for mission evaluation is the mass required to be placed in Earth orbit (MEO). MEO versus trip duration is plotted for various trajectory leg combinations of swingby missions in 1978, 1979, and 1983. MEO values for these missions as well as for swingbys in 1984 and 1986 are compared to those for the opposition class missions in the same time period. Nuclear propulsion and aerodynamic braking at Mars are considered. Results indicate that the timing incompatibilities associated with the #5-type swingby missions are more severe than is currently appreciated. By virtue of the availability of only #5-type swingby missions in 1978 and 1984, attractive swingby missions are not available during each opposition period to reduce the MEO requirement over direct missions. It is found that MEO requirements of the 1979 and 1983 swingby missions and the 1986 opposition class direct mission are all very nearly equal for a given propulsion mode. Aerodynamic braking at Mars can yield mass savings of up to 60 per cent.

INTRODUCTION

Launch opportunities for direct round trip flights to Mars occur periodically with the Mars opposition cycle. However, the mass required in initially Earth orbit (MEO) is strongly dependent upon Mars' relative position in its eccentric orbit--the least mass being required for encounters near Mars' perihelion. A tabulation of Mars opposition dates and their associated heliocentric longitudes shows that fifteen oppositions comprising thirty-two years are required before the angular position cycle

+ Member of Technical Staff, Bellcomm, Inc., Washington, D. C.

is approximately repeated.* On the average, then, an opposition period requires about 2.1 years, during which time the heliocentric angle advances forty-eight degrees.

The five oppositions from 1978 through 1987, in addition to spanning an era in which manned Mars missions will probably be of prime interest, also span the range of launch difficulty with respect to propulsion requirements. Opposition-class trips typically arrive at Mars shortly after the date of opposition. It is noted in Fig. 1 that in the 1978 mission Mars is encountered just eight degrees beyond Mars' aphelion, while in 1986 encounter occurs at a true anomaly of thirteen degrees. The lengths of the position vectors illustrate the strong variation in mass requirements associated with the respective launch opportunities. It is seen that for the vehicle parameters assumed a three-to-one variation exists between the 1978 and 1986 opportunities.

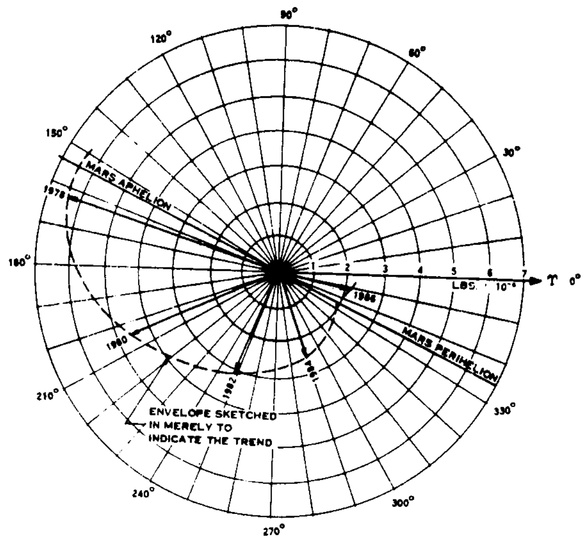


FIG. 1 MEO AS A FUNCTION OF MARS ARRIVAL ANOMALY FOR THE 1978 – 1986 DIRECT FLIGHT MANNED MARS MISSIONS (C-C-C-CA MODE)+

The MEO variation with opposition year is considerably less pronounced when nuclear propulsion systems and/or aerodynamic braking at Mars is considered (Fig. 2). However, these modes are not now operational, and other means of providing realistic launch opportunities for each opposition period should be sought.

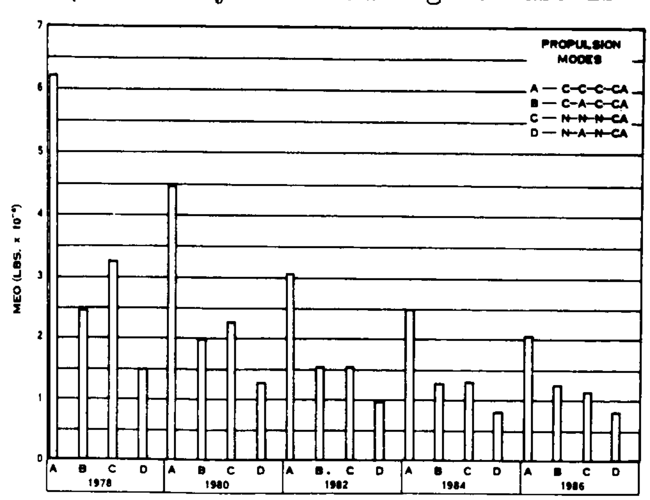


FIG. 2 MEO VARIATION WITH OPPOSITION YEAR FOR DIRECT MISSIONS.

The Venus swingby mode, as it was called by Sohn[1] in 1963, utilizes a close approach to Venus on one of the trajectory

* The MEO cycle requires approximately sixteen years.

+ See Table 1 for propulsion mode nomenclature.

legs to favorably perturb the trajectory and reduce the high Earth arrival velocities associated with the direct mission mode. The feasibility of this mode has been demonstrated by a number of authors in studies that investigate the availability of Venus for this purpose and determine the extent of mass savings that may be realized for specific missions. Deerwester[2] analyzed swingby missions in 1975, 1978 and 1980 to establish minimum mass requirements for comparison with direct mission requirements, and he presented the method of graphically displaying the swingby trajectory data currently in use.

This paper investigates in depth swingby missions during the 1978, 1980 and 1982 opposition periods with supplementary data for those of 1984 and 1986. The intent is to learn more about the effect on MEO of varying swingby parameters, such as Venus passage date, first and second leg transit time, total trip duration and stopover time, and also to note any shift of the optimum caused by changes in propulsion modes.

VENUS SWINGBY MISSION OPPORTUNITIES

As stated earlier, fifteen Mars oppositions comprising thirty-two years is required for the same Sun-Earth-Mars configuration (syzygy) to approximately repeat itself in absolute space. This syzygistic cycle--to use the nomenclature of Gillespie and Ross[3]--also includes the planet Venus, which comes into alignment with Mars seven times during each three Mars-Earth opposition periods--one syzygistic period. Once during each syzygistic period the same relative position of the three planets is repeated, and once each cycle their positions are repeated absolutely.

Gillespie and Ross classified the various types of Venus swingby missions (for either outbound or homebound Venus encounters) according to the number of its associated Mars-Venus alignment from the reference date of August 24, 1978 (JD 244 7032), when the three planets and the Sun are all in alignment. Of the seven types theoretically possible only the #3- and #5-types survive the practical analyses of timing compatibility and competition with direct mission opportunities.

As was seen in Figs. 1 and 2 for the direct missions, launch favorability improves from the worst case in 1978 to the most favorable case in 1986. Therefore, Venus swingby missions in the late 1970's and early 1980's are likely to reduce the mass requirements more significantly than those in the mid 1980's when direct mission opportunities are favorable.

In order to represent a general cross-section of Venus swingby missions without requiring inordinate amounts of computation, the missions and modes listed in Table 1 were selected. (The dates correspond to Mars-Venus alignments.) The November 27, 1984 homebound #5 and October 23, 1985 outbound #3 trajectory parameters were obtained from Ref. 3 without optimization, but were run under common ground rules to present comparable data for the full range of direct mission launch favorability.

Table 1

VENUS SWINGBY MISSIONS STUDIED

Mission	Propulsion Mode*	Stopover Time
June 27, 1978 Homebound No. 5	N-N-N-CA	10 Days
	N-A-N-CA	10 Days
June 9, 1979 Outbound No. 3	C-C-C-CA	8 - 13 Days
	C-A-C-CA	8 - 13 Days
	N-N-N-CA	8 - 13 Days
	N-A-N-CA	8 - 13 Days
January 31, 1983 Homebound No. 3	C-C-C-CA	10 Days
	C-A-C-CA	10 Days
	N-N-N-CA	10 & 20 Days
	N-A-N-CA	10 Days
November 27, 1984 Homebound No. 5	C-C-C-CA	18 Days
October 23, 1985 Outbound No. 3	C-C-C-CA	29 Days

*C--Chemical
N--Nuclear
A--Aerodynamic braking at Mars (totally)
CA--Chemical retro to 50,000 fps at Earth, if required, and aerodynamic braking from speeds up to 50,000 fps.
(The sequence is Earth escape-Mars retro-Mars escape-Earth retro and capture)

VELOCITY CONTOURS--TRAJECTORY SURFACES

The velocity contours were plotted from interpolated trajectory data generated with the Medium-Accuracy Interplanetary Transfer computer programs that were used to generate the data found in the "Planetary Space Flight Handbook".[4] Velocity contours, or more appropriately, trajectory surfaces upon which curves of constant velocity are plotted, are shown for both the direct and swingby legs for each of the missions considered. When properly paired, these surfaces represent mathematically possibly trajectory-leg combinations, which comprise round trips to Mars and pass close to Venus. Practical considerations restrict the surface areas of interest to those regions at which the departure and arrival velocities at both Mars and Earth are not prohibitively high and at which the trajectories are not required to pass through the planet Venus.

The direct-leg trajectory surfaces represent unique prograde trajectories for given date-pairs according to Lambert's law, which states that there exists a single heliocentric conic trajectory connecting two planets when the date of departure from the first planet and the date of arrival at the second planet are specified. However, since the swingby leg is itself a combination of two direct legs (matched by date and velocity at Venus), some regions of the swingby trajectory surfaces are double-valued; i.e., there exist two possible trajectories (that pass Venus at two different dates) for the same Earth-Mars date-pairs. These regions are characterized by crossing of the velocity contours (e.g., see Fig. 7), when the three-dimensional surface is projected on a plane in the conventional manner. In most cases, fortunately, the double-valued regions lay outside of the areas of practical significance by reason of insufficient Venus passage distance or excessive velocity. However, cases have been encountered in which surface undulations obscure regions of possible interest because of the manner in which the surfaces was projected for illustration. Fig. 3B shows a region of possible interest, which when plotted in the conventional manner is viewed almost tangentially to the surface. The trajectory details are seen to merge to the extent that they cannot be accurately interpreted. By plotting the surface in terms of Venus passage date, which rotates this surface by ninety degrees, a new projection is obtained which presents the data clearly (Fig. 3C).

The #5-type Venus swingby trajectory surfaces, in particular, undulate so wildly, possessing high ridges and plateaus and deep valleys, that it is difficult to assess whether or not all areas of practical interest have been investigated. Indeed, a region of perfectly acceptable trajectories in addition to those presented exists for the 1978 homebound #5 with almost identical velocity requirements, but with trip durations extended by about one-hundred days.

MISSION PROFILE AND VEHICLE CONSTRAINTS

The primary criterion for mission evaluation is the mass required to be placed in Earth parking orbit by the launch vehicle, which, obviously, depends upon the assumptions made regarding vehicle propulsion parameters for each stage of the mission. However, since this paper is not concerned with establishing an accurate set of launch vehicle design specifications, little significance should be placed upon the performance parameters assumed for the basic vehicle as long as they represent values that are attainable, or nearly so, in the time span of interest. Although the calculated values of MEO are given for the missions considered, the emphasis should be placed upon the variation in MEO and trip duration with operational mode and mission year. The mission profile, module weights, and propulsion parameters used in the MEO calculations are given in Table 2. Aerodynamic braking from speeds up to 50,000 fps is assumed at Earth arrival in all cases, and some missions consider aerodynamic braking at Mars

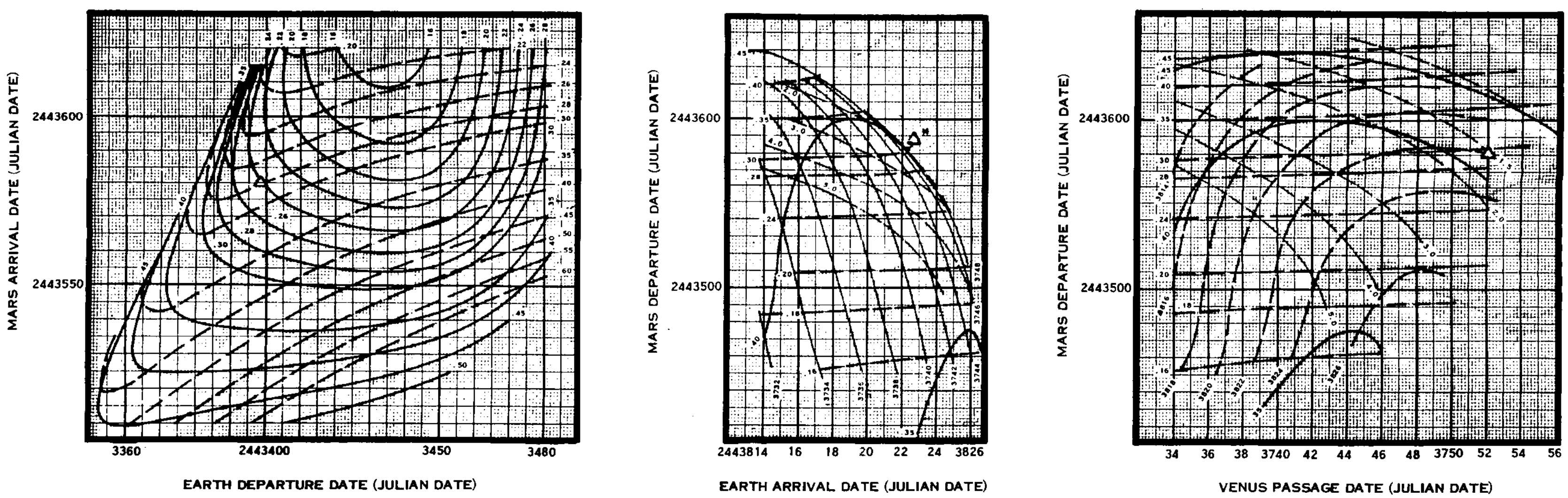
DIRECT OUTBOUND LEG

FIG. 3A

VENUS SWINGBY HOMEBOUND LEG

FIG. 3B

FIG. 3C



—— VELOCITIES AT EARTH (EMOS)

—·— VELOCITIES AT MARS (EMOS)

Δ YIELDS MINIMUM MEO

— — CONSTANT EARTH ARRIVAL DATE (JULIAN DATE PLUS 2440000)

* HIDDEN BY SURFACE

— — VENUS PASSAGE DATE (JULIAN DATE PLUS 2440000)

— — VENUS PASSAGE DISTANCE (VENUSIAN RADII)

FIG. 3 TRAJECTORY SURFACES OF THE 25 JUN 1978 HOMEBOUND #5 VENUS SWINGBY MISSION as well. In the latter case a 500 fps ΔV allowance was assumed for maneuvering to achieve the desired Martian parking orbit. Ideal ΔV's were corrected for gravity-losses by reference to curves prepared from integrated-trajectory data. Nuclear propulsion was considered for a few reference missions for comparison purposes.

Table 2

MISSION CONSTRAINTS

Mission Profile

Escape from 100 nm Earth parking orbit.
Retro or aerodynamically brake into Mars parking orbit.
Descent and Ascent propulsion system weights including in MEM weight. Allow 500 ft/sec maneuvering ΔV at Mars for purposes of parking orbit correction when aero-braking mode is used.
Escape from 100 nm Martian parking orbit.
Aero-brake from speeds up to 50,000 fps at Earth arrival. Retro-thrust to 50,000 fps if necessary.

Module Weights

Mission Module (MMM)	90,000 lbs
Excursion Module (MEM)	47,500 lbs
Recovery Capsule (Not including heat shield)	10,000 lbs
Expendable Usage Rate	50 lbs/day
Heat Shield weights in accordance with Ref. 5	

Propulsion Parameters

	Chemical		Nuclear			
	I_{sp}	λ	I_{sp}	λ	T/W_e	T/W_t
Earth Escape	465	.94	800	.85	6	.25
Mars Retro	465	.92	800	.84	6	.10
	330*	.90*				
Mars Escape	465	.92	800	.84	6	.25
Earth Retro	465	.86				

I_{sp} - specific impulse
λ - mass fraction
T/W_e - thrust/engine weight
T/W_t - thrust/total weight
* - storable propellant for 500 fps maneuvering ΔV during Mars aero-braking.

MEO DETERMINATION

The purpose of plotting the velocity contours is to provide the mission analyst with a graphic display of possible trajectories from which he can select optimum round trips on a velocity basis. Since vehicle performance parameters and propulsion mode affect the optimum trajectory based on minimum MEO, this trajectory cannot be readily determined, and although it yields a lower bound on the mass requirement for a particular mission year and establishes representative leg and trip times, the minimum MEO trajectory yields no insight into the effects of mission variations.

In order to determine the effect of variations in launch date, Mars arrival date, stopover time, Venus passage date, and trip duration, a series of trajectories were selected which span the regions of primary interest on the trajectory surfaces. For a given Mars stopover time the desired trajectory variations were obtained by changing Venus passage date, Mars arrival date, and Earth departure date in turn. The corresponding trajectory information was used with a spacecraft weight computer program to yield the desired array of MEO values.

RESULTS

1978 Homebound #5 Venus Swingby Mission

As stated in the introduction, it would appear that because the mass requirements for the opposition class direct missions in 1978 are prohibitively high (greater than 6-million lbs for the C-C-C-CA* mode), the Venus swingby mode would demonstrate its greatest mass-savings potential during this mission year. However, this is not the case. Timing problems are encountered at Mars to the extent that low energy round trips would require the spacecraft to leave Mars prior to its arrival there. Since at least a short stopover period was assumed for the basic mission philosophy, the existing timing incompatibility was accepted, and the best trajectory-leg combination was determined on a minimum-mass basis.

Fig. 4 shows the mass variation with Venus passage date for three Earth

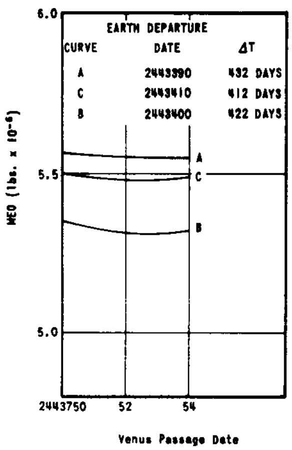


FIGURE 4. MEO VARIATION WITH VENUS PASSAGE DATE FOR 3 EARTH DEPARTURE DATES FOR THE 1978 HOMEBOUND #5 VENUS SWINGBY MISSION (N-N-N-CA MODE)

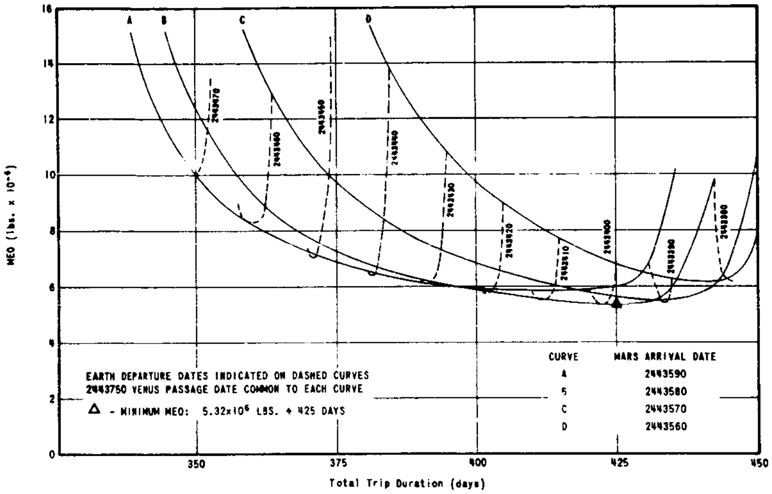


FIGURE 5. MEO VARIATION WITH EARTH DEPARTURE DATE FOR VARIOUS MARS ARRIVAL DATES FOR THE 1978 HOMEBOUND #5 VENUS SWINGBY MISSION (N-N-N-CA MODE)

departure dates and reveals that the optimum passage date occurs just after JD 244 3752. Because more data was available for a passage date of JD 244 3750, this date was used and held constant for the curves of Fig. 5, which illustrate the MEO variation with Earth departure date for four Mars arrival dates.+ The minimum MEO trajectory is indicated by the marker and identifies JD 244 3580 as the optimum Mars arrival date. These two dates define the optimum swingby trajectory and the Mars arrival date for the direct outbound leg. The MEO variation with Earth departure date is shown in Fig. 6. This curve can be construed to represent the effect of launch delays, because the timing incompatibility at Mars places a constraint on the arrival and departure dates at Mars and, hence, on the swingby trajectory. Trip duration is, therefore, directly related

* See Table 1 for propulsion mode descriptions.

+ Or four Mars departure dates, since 10-day staytimes were used.

to Earth departure date--a result demonstrated by the equal spacing between the abscissas of the points on the curve. It is also noted in this figure that early launches of more than ten days result in considerably higher MEO requirements. This effect may be explained by referring to Fig. 3A and noting that these trajectories lie near the 180°-transfer ridge where they are highly inclined to the ecliptic plane.

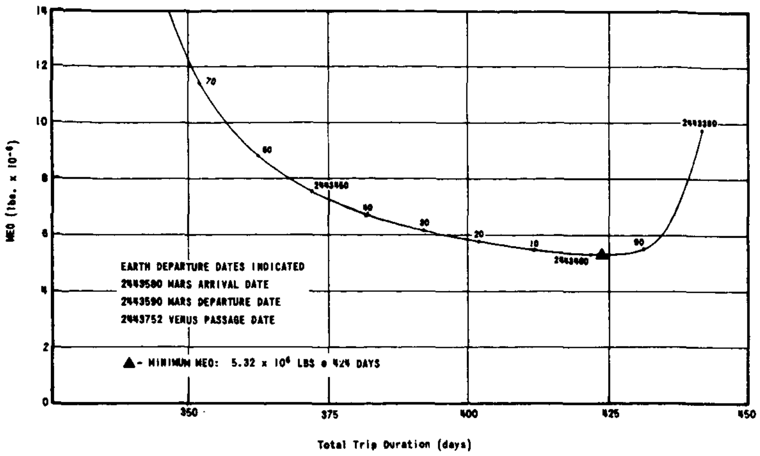


FIGURE 6. MEO VARIATION WITH EARTH DEPARTURE DATE FOR THE 1978 HOMEBOUND #5 VENUS SWINGBY MISSION (N-N-N-CA MODE)

The effect of changing the Venus passage date from JD 244 3750 to JD 244 3752 is not noticeable in the MEO results, and both swingby trajectories arrive at Earth within one-tenth of a Julian day of each other. The change results in a closer passage distance and greater bend angle at Venus, causing the trajectory to terminate at the same heliocentric position at Earth encounter.

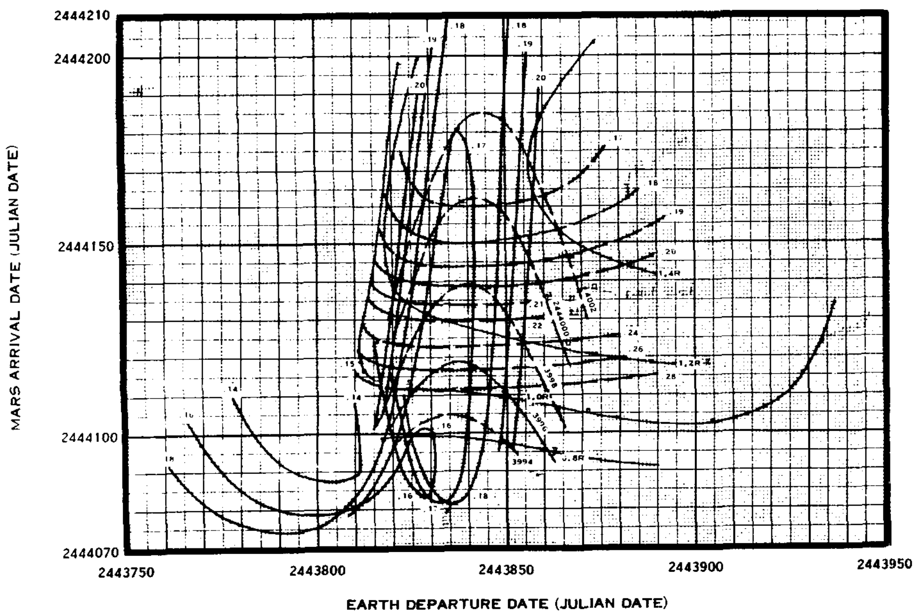
The trajectory data representing the minimum-MEO trip for the 1978 N-N-N-CA mission is given in Table 3. It is noted that the mass requirement remains prohibitively high--higher than for opposition class missions. However, since relatively short trip durations are required ($\sim$ 425 days), if other means of reducing MEO (e.g., elliptical Martian parking orbits or aerodynamic braking at Mars) could be provided, this mission year could yield an attractive launch opportunity.

<u>1979 Outbound #3 Venus Swingby Mission</u>

Some difficulty was encountered in plotting and interpreting the 1979 outbound #3 trajectory surfaces, because some of the velocity contours of the swingby surface appeared to cross each other (Fig. 7A). A three-dimensional plot was made (Fig. 8), which reveals that the surface is saddle-shaped and has a large usable region extending upward from the 1.0 Venusian radius contour.

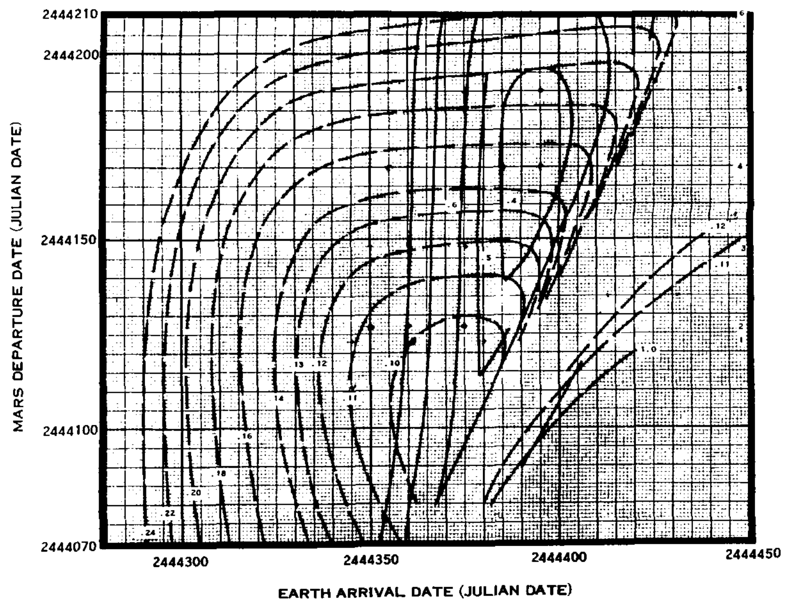
Fig. 9 shows that the optimum Venus passage date on a minimum-mass basis is JD 244 4000 for the three Earth departure dates indicated, when the

FIG. 7A



EARTH DEPARTURE VELOCITY (EMOS)
MARS ARRIVAL VELOCITY (EMOS)
VENUS PASSAGE DATE (JULIAN DATE)
VENUS PASSAGE DISTANCE (VENUSIAN RADII)

FIG. 7B



MARS DEPARTURE VELOCITY (EMOS)
EARTH ARRIVAL VELOCITY (EMOS)

FIG. 7 TRAJECTORY SURFACES OF THE 9 JUN 1979 OUTBOUND #3 VENUS SWINGBY MISSION

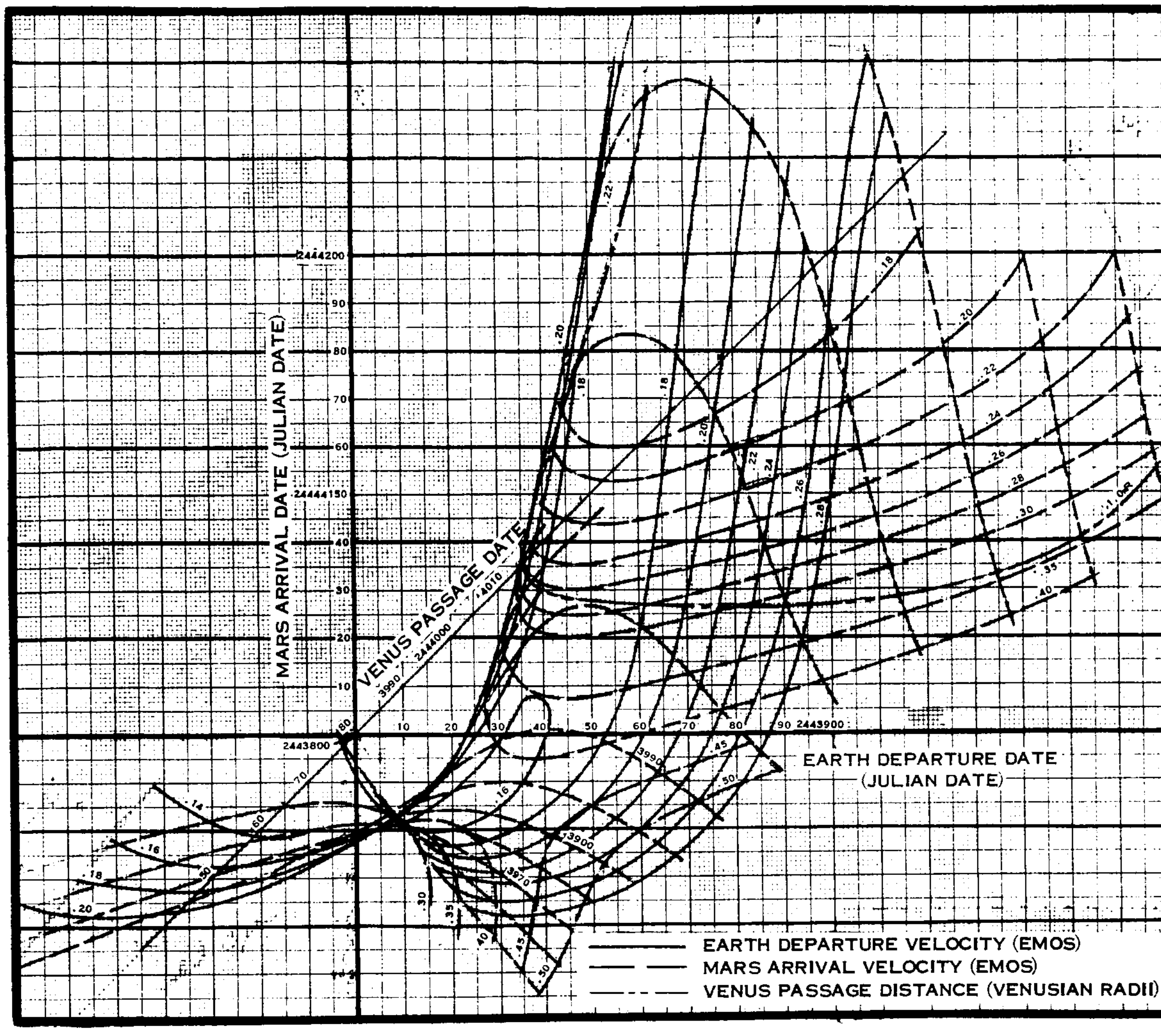


FIG. 8 3-DIMENSIONAL ILLUSTRATION OF THE 9 JUN 1979 OUTBOUND #3 VENUS SWINGBY TRAJECTORY SURFACE

C-C-C-CA propulsion mode is used. These dates correspond to trajectories that lie in the ridge region of the saddle-shaped surface, where departure velocities are at their minimum for a given Mars arrival date. By specifying an Earth departure date and a Venus passage date, the outbound swingby trajectory and, hence, the Mars arrival date is determined. Trajectory variations can then be made on the direct homebound leg. Fig. 10 shows the MEO variation as a function of Earth arrival date for the three swingby trajectories considered. The dashed curves represent homebound trips of equal duration. The flatness of these curves can be explained by analysis of Figs. 11 and 7. Earth, at a typical arrival date, is in such a position relative to Mars at the Mars departure date that essentially the same Mars departure conditions exist for a whole series of trajectories associated with incremented trip durations. This theory is graphically confirmed in Fig. 7B by the lack of any appreciable Mars departure velocity gradient for Earth arrival dates between JD 244 4350 and JD 244 4400. In addition, the assumption was made that Earth entry would be accomplished by aerodynamically braking from speeds up to 50,000 fps, which nullifies* the effect of crossing the existing Earth arrival velocity contours in the direction of their steepest gradient. The minimum-MEO trajectory is listed in Table 3.

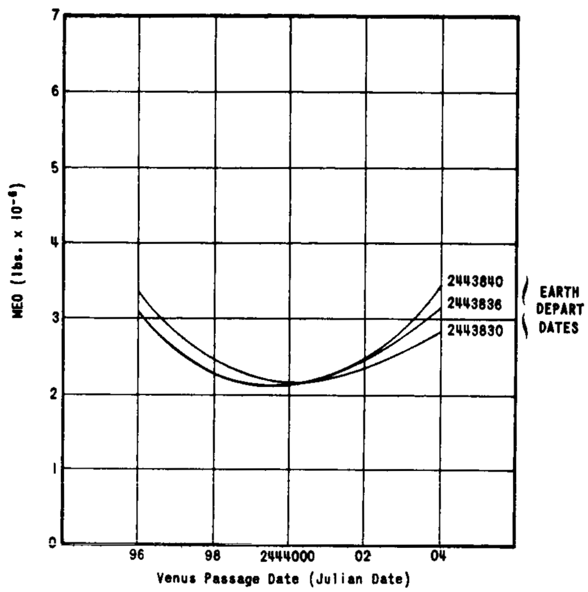


FIGURE 9. MEO VARIATION WITH VENUS PASSAGE DATE FOR 3 EARTH DEPARTURE DATES FOR THE 1979 C-C-C-CA VENUS SWINGBY MISSION

A similar set of curves is shown for the C-C-C-CA mode in Fig. 12. For this case an additional Earth departure date was considered to illustrate the effect of leaving the ridge area of the swingby trajectory surface. The most significant effect of changing propulsion modes, aside from the derived reduction in MEO requirements, is the extent to which the trajectory parameters are biased toward earlier Mars arrival and departure dates while maintaining equivalent trip durations. Here, again, the steep velocity gradient is nullified by means of aero-braking to the extent that the outbound swingby trip is shortened some forty days and the direct homebound leg is lengthened by the same amount (producing a more nearly Hohmann-type transfer back to Earth). Fig. 13 shows the optimum MEO vs. ΔT curves for the various propulsion modes considered.

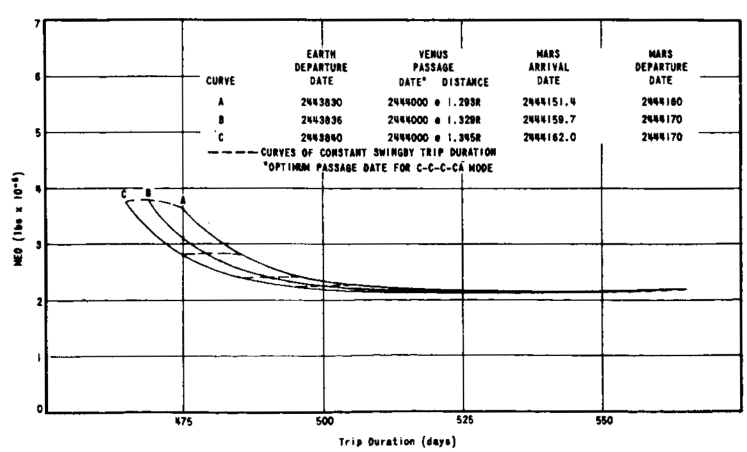


FIGURE 10. MEO VS. ΔT FOR VARIOUS TRAJECTORIES PASSING VENUS AT 2444000 J.D.* (1979 C-C-C-CA VENUS SWINGBY MISSION)

* Except for small changes in heat-shield weight.

1983 Homebound #3 Venus Swingby Mission

The 1983 Homebound #3 swingby trajectory surface is seen in Fig. 14 to be well-defined with minimum Mars departure velocities occuring at Mars departure dates of approximately JD 244 5243, if return trips of 300-days duration are allowed. However, the direct-leg surface shows that the trajectory parameters are biased toward somewhat earlier Mars arrival dates, and the trade-off optimizes at a JD 244 5222 arrival for a ten day stopover period. Fig. 15 shows the MEO vs. ΔT variation as functions of Venus passage date, Mars arrival date, and Earth departure date. The "tails" on the Earth departure and Mars arrival curves are due to encounter with the 180°-transfer ridge on the direct-leg trajectory surface. Data regarding the minimum-mass trajectory is found in Table 3.

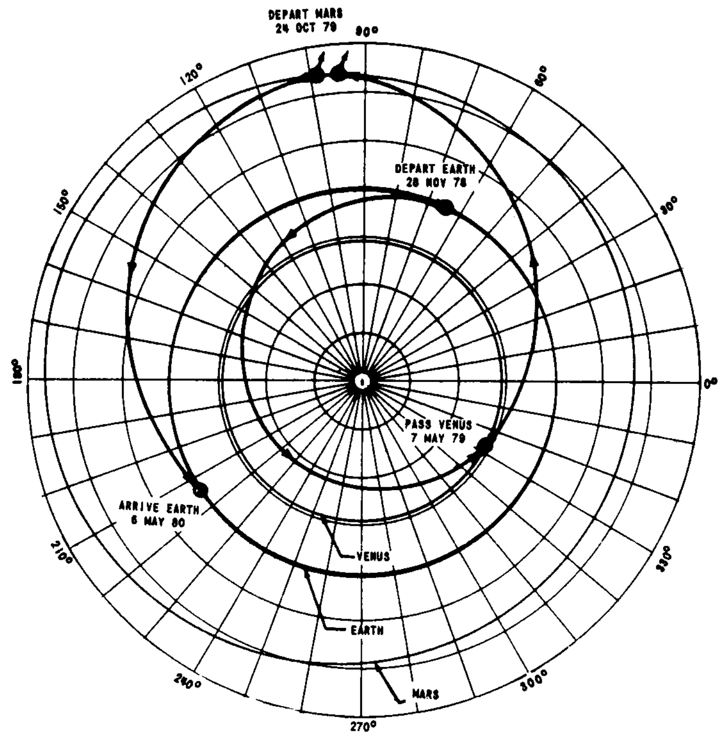


FIGURE 11. MISSION PLAN OF THE 1979 OUTBOUND #3 VENUS SWINGBY MISSION

A comparison was made between 10- and 20-day stopover periods at Mars using nuclear propulsion, and the results indicate that the swingby leg is shortened by about twenty days to achieve a 2.3% reduction in MEO.

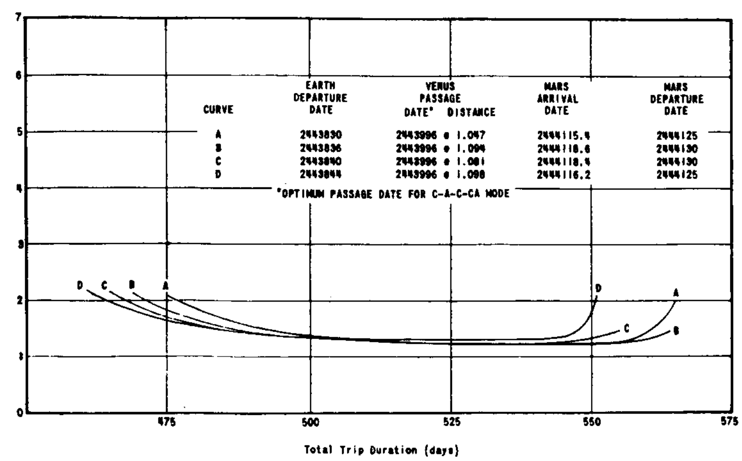


FIGURE 12. MEO VS. ΔT FOR VARIOUS TRAJECTORIES PASSING VENUS AT 2443996 J.D. (1979 C-A-C-CA VENUS SWINGBY MISSION)

1984 Homebound #5 and 1985 Outbound #3 Venus Swingby Missions

Based on the swingby trajectory surfaces illustrated in Ref. 3, velocities and dates representing typical trajectories for the 1984 homebound #5 and 1985 outbound #3 Venus swingby missions were selected to determine corresponding MEO's. The first 1984 trajectory used in the mass calculations resulted in an MEO requirement in excess of 5-million lbs, which did not appear at all reasonable in view of the downward trend of mission requirements with opposition year. The trajectory data were more closely analyzed to obtain better trajectory parameters, and the resulting mass requirement in orbit was found to be 4.6-million lbs. While this value still remains inordinately high for a 1984-5 mission year, it must be remembered that the mission considered is a #5-type with its inherent timing incompatibility at Mars. Also, when compared with the similar #5 mission in 1978 using the chemical mode, it is realized that a reduction by a factor or two was achieved by changing the mission year.

The single trajectory analyzed for the 1985 outbound #3 mission resulted in an MEO requirement of just over 2-million lbs

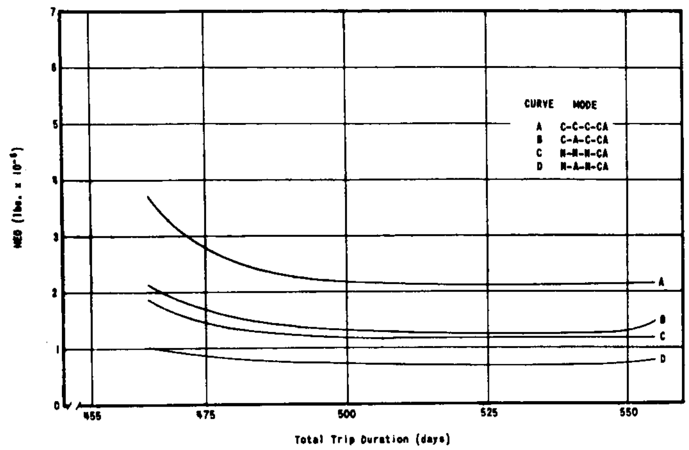


FIGURE 13. OPTIMUM MEO VS. ΔT CURVES FOR VARIOUS PROPULSION MODES OF THE 1979 VENUS SWINGBY MISSION

Table 3

MINIMUM-MEO TRAJECTORIES

Event	Julian Date	Calendar Date	Terminal Velocity (emos)	
25 Jun 1978 Homebound #5, N-N-N-CA Mode, 424-Days, 5.32-million lbs				
Earth Departure	244 3398	12 Sep 1977	.2417	
Mars Arrival	244 3580	13 Mar 1978	.2819	
Mars Departure	244 3590	23 Mar 1978	.2937	
Venus Passage	244 3752	1 Sep 1978	.2522	@1.658R
Earth Arrival	244 3822	10 Nov 1978	.4111	
9 Jun 1979 Outbound #3, C-C-C-CA Mode, 525-Days, 2.12-million lbs				
Earth Departure	244 3840	28 Nov 1978	.1687	
Venus Passage	244 4000	7 May 1979	.3338	@1.345R
Mars Arrival	244 4162	16 Oct 1979	.1685	
Mars Departure	244 4170	24 Oct 1979	.1509	
Earth Arrival	244 4365	6 May 1980	.1871	
31 Jan 1983 Homebound #3, C-C-C-CA Mode, 550-Days, 2.27-million lbs				
Earth Departure	244 4982	13 Jan 1982	.1502	
Mars Arrival	244 5222	10 Sep 1982	.1298	
Mars Departure	244 5232	20 Sep 1982	.2141	
Venus Passage	244 5387	22 Feb 1983	.3878	@1.854R
Earth Arrival	244 5532	17 Jul 1983	.2099	
27 Nov 1984 Homebound #5, C-C-C-CA Mode, 464-Days, 4.59-million lbs				
Earth Departure	244 5750	20 Feb 1984	.1350	
Mars Arrival	244 5896	6 Apr 1984	.2750	
Mars Departure	244 5914	2 Aug 1984	.1762	
Venus Passage	244 6084	19 Jan 1985		@1.6R
Earth Arrival	244 6214	29 May 1985	.1300	
23 Oct 1985 Outbound #3, C-C-C-CA Mode, 560-Days, 2.02-million lbs				
Earth Departure	244 6150	26 Mar 1985	.14	
Venus Passage	244 6315	8 Sep 1985		@1.6R
Mars Arrival	244 6490	1 Mar 1986	.20	
Mars Departure	244 6519	30 Mar 1986	.11	
Earth Arrival	244 6710	7 Oct 1986	.11	

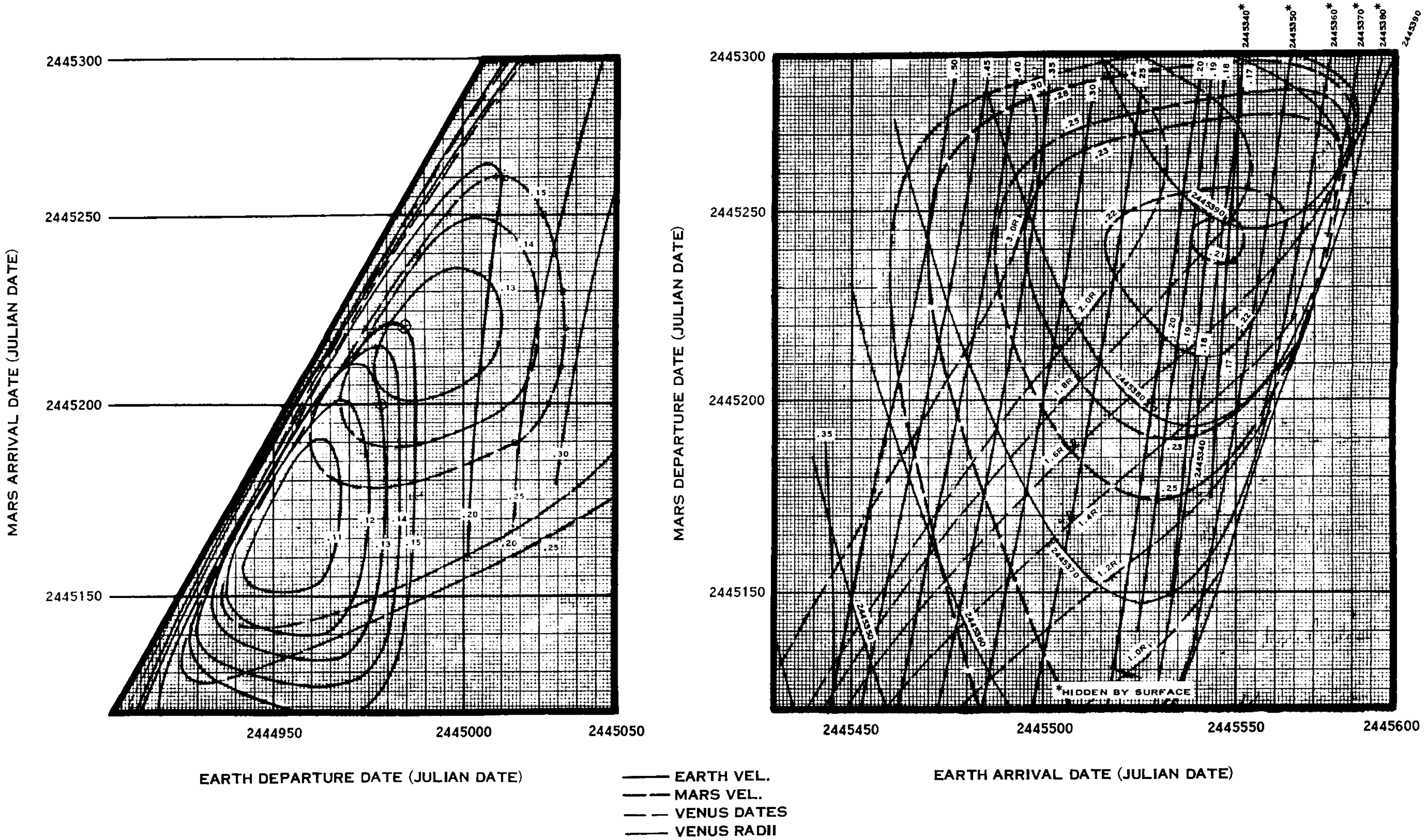


FIG. 14 TRAJECTORY SURFACES OF THE 31 JAN 1983 HOMEBOUND #3 SWINGBY MISSION

for the chemical mode. This value appears reasonable in view of the 1979 and 1983 #3 missions, and no attempt was made to optimize the mission.

MEO requirements for each mission considered are compared with opposition class missions in Fig. 16.

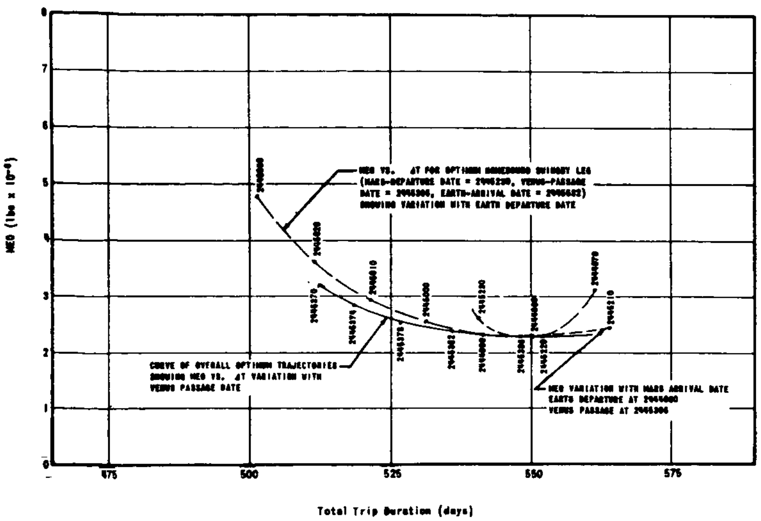


FIGURE 15. OPTIMUM TRAJECTORY CURVES FOR THE 1983 HOMEBOUND #3 VENUS SWINGBY MISSION (C-C-C-CA MODE)

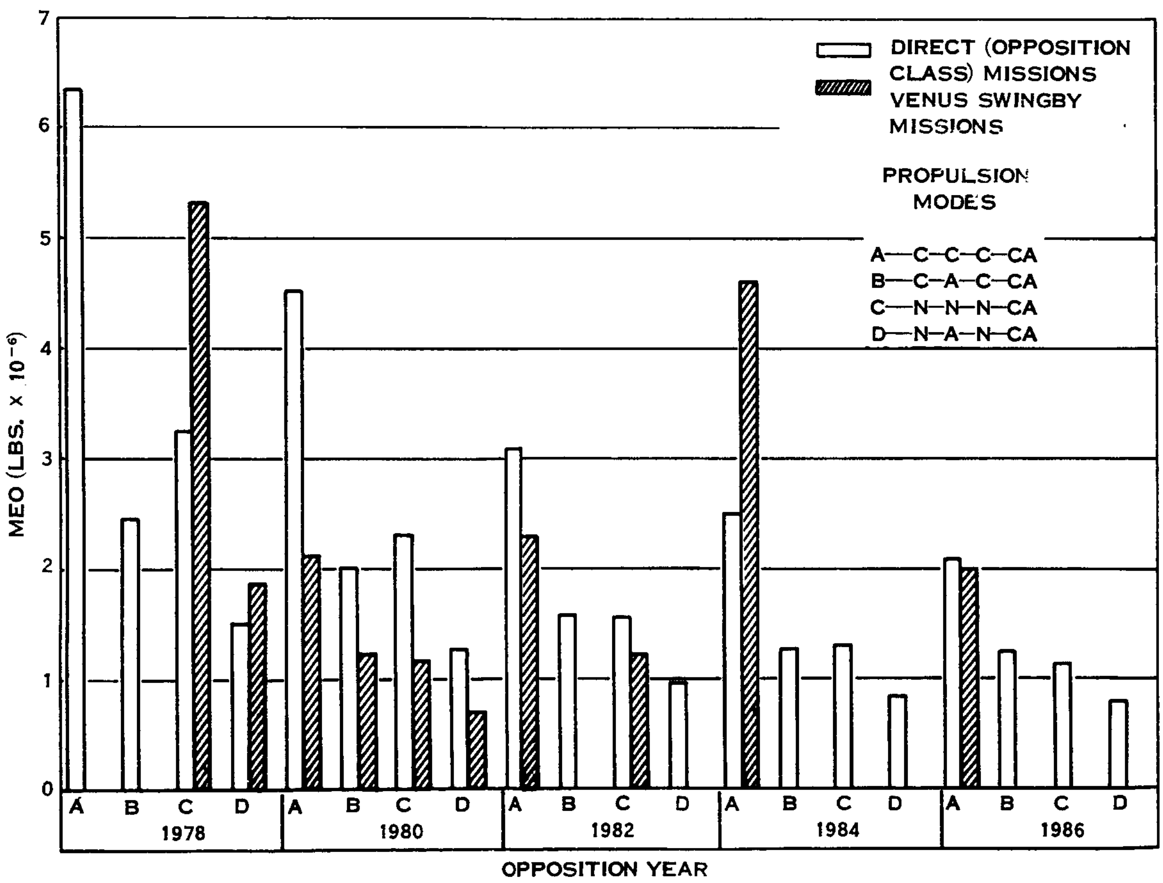


FIG. 16 MEO REQUIREMENTS FOR DIRECT AND SWINGBY MISSIONS FOR THE 1978 - 1986 OPPORTUNITIES

CONCLUSIONS

A number of conclusions can be made regarding Venus swingby missions in general based on the set of missions studied here:

1. The Venus swingby mode does not provide attractive launch opportunities for all opposition years without recourse to nuclear propulsion or aerodynamic braking at Mars, because of the timing incompatibilities associated with the #5-type missions.

2. The timing incompatibility at Mars associated with the homebound #5-type missions is more severe than is indicated in the available literature, and, based on the data presented in Ref. 3, it appears that the outbound #5-type missions suffer from timing incompatibilities just as severely as do the homebound types.

3. The mass requirements of the 1979 outbound #3 swingby, 1983 homebound #3 swingby, and the 1986 direct missions are all very nearly equal for a given propulsion mode. The significance of this result is that a vehicle designed for the minimum requirements of any opposition class mission could as well be used in 1979 or 1982 for Venus swingby missions.

4. Aerodynamic braking at Mars yields mass savings of up to 60%, depending on mission year and propulsion mode.

5. The effect of variations in stopover duration must be investigated for the specific mission under consideration but is found to vary with propulsion mode.

ACKNOWLEDGMENT

The author's appreciation is expressed to Howard S. London, Bellcomm, Inc., for his direction of this study, to Dr. Stanley Ross, NASA ERC, for furnishing the basic trajectory programs and Venus passage dates of interest, and to Stewart M. Manville, Bellcomm, Inc., for his capable programming assistance.

REFERENCES

1. Sohn, R. L., "Summary of Manned Mars Mission Study," Part 5 of Proceedings of the Symposium on Manned Planetary Missions, 1963/1964 Status; NASA TX-53049, June 12, 1964.

2. Deerwester, J. M., "Initial Mass Savings Associated with the Venus Swingby Mode of Mars Round Trips," AIAA 2nd Aerospace Sciences Meeting, Paper No. 65-89, 1965.

3. Gillespie, R. W. and Ross, S., "The Venus Swingby Mission and Its Role in the Manned Exploration of Mars," AIAA 3rd Aerospace Sciences Meeting, Paper No. 66-37, 1966.

4. Lockheed Missiles & Space Company, prepared for the George C. Marshall Space Flight Center under NAS8-2469, Space Flight Handbooks, Vol. 3--Planetary Flight Handbook, NASA SP-35, 1963.

5. TRW Space Technology Laboratories, prepared for the George C. Marshall Space Flight Center under NAS8-5371, Final Report: Mission Oriented Advanced Nuclear System Parameters Study, 8423-6010-RU000, 1965.